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Comment on "Self-Heating versus Quantum Creep in Bulk Superconductors"

In their recent Letter Gerber and Franse [1] argue that in bulk high- T_c superconductors the nonvanishing magnetization relaxation at low temperatures is not due to quantum tunneling but to self-heating effects. In a nice experiment they confirm the well-known fact that the dissipation associated with the movement of vortices leads *under adiabatic conditions* to a rise of the temperature of the sample. Contrary [2] to their Eq. (1), the dissipated power P is given by the integral over the sample volume of $\mathbf{j} \cdot \mathbf{E}$ where \mathbf{j} is the current density and $\mathbf{E} = \mathbf{B} \times \mathbf{v}$ (where \mathbf{v} is the velocity of the vortices and \mathbf{B} the local magnetic induction). For a disk shaped sample of radius R and thickness D the magnetic moment is $M \cong jR^3D$ and during creep $P \cong t^{-1} \mu_0 j^2 R^3 D^2 (d \ln M / d \ln t)$ where the time t is measured from the start of the relaxation. The relaxation rate is typically $d \ln M / d \ln t = 10^{-2}$. For $R = 1.3 \times 10^{-3}$ m, $D = 10^{-4}$ m and $j = 5 \times 10^9$ A/m² which is typical for BiSrCaCuO at 1 T and low temperatures we obtain at $t = 5000$ s, $P \cong 1.4$ nW, and $dP/dt \cong -0.3$ pW/s, of the same order of magnitude as in [1].

The authors calculate the temperature profile inside the sample in the case of a phonon dominated thermal conductivity $k = \alpha T^3$ with $\alpha = 0.25$ W/mK⁴ and conclude from their Eq. (3) that T_i , the temperature in the center of the sample, can be drastically larger than its surface temperature T_s . For example, for a cubic sample with side $l = 5 \times 10^{-4}$ m and a power dissipation $P = 1.5$ nW they find $T_i = 0.112$ and 12.01 K for $T_s = 0.1$ and 0.01 K, respectively. They conclude, therefore, that low-temperature relaxation is due to an internal self-heating effect.

In this Comment we show that there are three strong reasons to believe that the conclusions of Gerber and Franse are wrong.

(1) From their analysis (and *a fortiori* from the correct analysis given below) thin films should not suffer from significant self-heating effects. Hence, if self-heating were important one would observe in thin films a different behavior from single crystals, in contradiction with existing data for YBa₂Cu₃O₇ where $d \ln M / d \ln t$ at low temperatures is of the same order of magnitude for films and bulk single crystals [3].

(2) Equation (3) in Gerber and Franse's paper is not the correct solution for a cubic sample of side l with a heat source of power P on one of the faces. Treating the heat conduction in a one-dimensional approximation they calculate the temperature T_i of the face where P is pumped into the sample as a function of the bath temperature T_s of the opposite face. In a stationary state the same power P is transferred through any cross-sectional

area l^2 of the sample, i.e., $P = kl^2(dT/dx)$. With $k = \alpha T^3$ one obtains after integration that

$$T_i = (T_s^4 + 4P/\alpha l)^{1/4}, \quad (1)$$

which reduces to $T_i = (T_s^4 + 4.8 \times 10^{-5})^{1/4}$ for $P = 1.5$ nW and $l = 5 \times 10^{-4}$ m. At all $T < 10$ mK this leads to $T_i \cong 83$ mK, instead of $T_i > 12.01$ K found by Gerber and Franse by using their Eq. (3).

(3) For both YBa₂Cu₃O₇ films and single crystals M exhibits logarithmic time decay and $d \ln M / d \ln t$ remains essentially constant over many decades in time. Below a certain temperature T^* (typically $T^* = 1$ K) $d \ln M / d \ln t$ is experimentally found to remain constant [3-5]. In the absence of quantum tunneling and for the measured dissipation one would expect (since in that case $d \ln M / d \ln t \propto T$) a plateau below 83 mK [see point (2)] instead of 1 K as observed experimentally. In order to have $T_i = T^* \cong 1$ K one would need a power dissipation which is more than 2×10^4 times larger, i.e., ≈ 31 μ W.

In conclusion, self-heating by moving vortices is certainly *not* an essential obstacle for the observation of macroscopic quantum creep in bulk superconductors (by bulk we mean samples of typically $1 \times 1 \times 0.1$ mm³). It can easily be avoided by using films in good contact with the thermal bath. The second term in Eq. (1) is then proportional to D/R^2 (D is the film thickness, R its radius) instead of $1/l$ and hence is reduced by many orders of magnitude.

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